BEYOND ERROR REPORTING TOWARD RISK ASSESSMENT

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The Aviation Safety Monitoring and Modeling (ASMM) Project of NASA's Aviation Safety Program is developing a set of automated tools to facilitate efficient, comprehensive, and accurate analyses of data collected from large, heterogeneous databases throughout the National Aviation System. These data sources consist of qualitative data (textual, categorical, and survey data) and quantitative data (digital flight recorder data, radar track data). The ASMM technologies will establish meaningful linkages among these diverse data sources and enable visualization of significant patterns and trends. This paper reports on a recent demonstration of ASMM tools to extract information related to a potentially hazardous scenario encountered in air-carrier operations – changes to a landing runway assignment while an aircraft is on approach, and close to the airport. The existence of a possible problem with this event, dubbed an "In-Close Approach Change" (ICAC), was first identified by the Aviation Safety Reporting System (ASRS). The ICAC scenario was then analyzed by applying automated tools to several quantitative data sources. The goal was to demonstrate a process that assists the domain expert in gaining insight into the contextual factors that can lead to human error in ICAC events, and to enable a better assessment of the safety risk in these events. Each of the several ASMM tools has the potential of contributing insights into other types of safety events, and supporting a complementary and synergistic process of causal analysis and safety risk assessment.

Introduction

Air transportation is essential to continued economic development of the world. It is the most rapidly growing mode of transportation and it is one of the safest modes of travel. Nevertheless, the public demands that safety levels continuously improve and that the absolute number of aviation accidents continue to decline, even as air traffic levels increase.

Within NASA's Aviation Safety Program, the Aviation System Monitoring and Modeling (ASMM) project addresses the need to provide decision makers with the tools for safety improvement by identifying and correcting the predisposing conditions that could lead to accidents. A proactive approach to identifying and alleviating life-threatening conditions involves monitoring the system performance in a non-punitive environment, learning from normal operational experience, identifying the precursors that foreshadow most accidents, and designing appropriate interventions to minimize the risk of their occurrence.

Human error is often the proximate cause of aviation accidents and incidents, but more distal precursor conditions often contribute to those errors. Our focus is on precursor conditions that elevate the probability of downstream human errors that may, in turn, contribute to aviation safety incidents or accidents.

The ASMM Project is developing a set of automated tools to facilitate identification of precursor conditions and events, as well as operational trends that might compromise safety. This approach contrasts with others that are more concerned with the identification of specific human errors and the allocation of blame.

The ASMM Tools

In the process of proactively managing risk, aviation domain experts must set performance standards, compare performance to expectations, identify potential problems, and develop intervention strategies. Decision-makers must be able to focus quickly on those events with the highest potential severity and likelihood of reoccurrence. Automated tools, such as those developed by ASMM, can facilitate this work.

ASMM does not aim to replace human expertise with automation. Rather, it provides computational tools that focus the attention of human experts on the most significant events, and help them identify the factors that distinguish unsafe operations from routine flights. It has developed tools to do tasks that presently can only be performed with much time and effort by aviation experts. The purpose of the ASMM tools is to convert a bounty of raw aviation data drawn from many sources—aircraft flight data recorders, ATC radar tracks, maintenance logs, weather records, aviation safety incident reports, etc—into meaningful information, vividly displayed.

Qualitative data sources yield information that helps the analyst understand the subjective aspects of "why" an incident occurred, while quantitative data sources help the analyst to understand the objective aspects of "what" happened. Each of the ASMM tools contributes insights into the complete picture of an event and supports the complementary processes of causal analysis and safety-risk assessment.

The ASMM tool suite includes the following analytical resources:

- **PROFILER** identifies clusters of typical and atypical flights from flight-recorded or radar track digitized data, and characterizes typical and atypical operations. It also searches for and displays differences among flights. Atypical flights within normal operations may, or may not, point to unsafe conditions lurking in the aviation system. (Amidan, Cooley, *et al*, 2002; Amidan, Swickard, *et al*, 2002; Ferryman, 2001)The **AUTOMATIC LANGUAGE ANALYSIS NAVIGATOR (ALAN)** is a text comprehension tool that clusters textual data. ALAN identifies aviation safety reports that have similar topics, or identifies clusters of reports that are similar to a given exemplar. (Willse, *et al*, 2002)
- The **PATTERN SEARCH** tool is an aid to retrospective search of flight-recorded or radar track data that enables the user to define a pattern of multiple flight parameters, and search for that pattern in a large database. (Chidester, 2001)

The ASMM Source Databases

The first step in the cycle of proactive management of risk is to monitor the system continuously, and collect, codify, and classify safety incident data into repositories that can be subsequently mined for safety insights. Some of these databases, such as the Aviation Safety Reporting System (ASRS) and National Transportation Safety Board (NTSB) databases, reside in the public domain. Others, such as air carrier digital flight data archives, store closely held information. Accordingly, the ASMM uses a dual safety monitoring strategy. It is developing tools that help identify system-wide safety trends and influences using public domain data resources (*extramural monitoring*). It is simultaneously developing tools that enable complementary internal monitoring of flight and air traffic control operations by air carrier and air traffic control personnel (*intramural monitoring*).

The "extramural" monitoring element of ASMM is the National Aviation System Operational Monitoring Service (NAOMS), a system-wide survey tool. Currently, aviation databases capture information about specific parts of the National Aviation System (NAS), but no existing database addresses the health and safety of the NAS *as a whole*. NAOMS is establishing a new national capability that will *quantitatively* track aviation safety trends; monitor the impacts of technological and procedural changes to the NAS, and contribute to the development of a data-driven basis for safety decisions.

The "intramural" monitoring element is intended to provide air-service operators with the tools needed to monitor their performance continuously, effectively, and economically within their own organizations. The primary products of this activity are the Aviation Performance Measuring System (APMS) for processing aircraft flight-recorder data, and the Performance Data Analysis and Reporting System (PDARS) for processing air traffic control data.

APMS is developing tools and methodologies for commercial air carriers to manage, process, and analyze very large quantities of digital flight-recorded data in support of Flight Operations and Quality Assurance (FOQA) programs and Advanced Qualifications Programs (AQP). (Chidester, 2001)

PDARS is an ATC radar-track monitoring capability developed by NASA/ASMM and FAA that routinely collects, processes, and merges ATC data; computes quantitative performance measures; produces and disseminates daily performance-measurement reports. PDARS performance measurements relate to system throughput, delays, system predictability, and other key ATC performance indicators. (Shade *et al*, 2002)

ASMM also draws on ancillary data sources such as meteorological records to further develop its understanding of contextual factors contributing to safety events.

Another database that has been used as a resource for the ASMM Project is the Aviation Safety Reporting System (ASRS) that NASA has managed on behalf of the FAA for over 27 years. While the ASRS is not formally an activity of the Aviation Safety Program, our experience with ASRS stimulated and informed many ASMM research and development activities**A Case Study: In-Close Approach Changes (ICAC)**

During 2002, a milestone was achieved with the application of some ASMM computational tools and methods to a potentially hazardous scenario encountered in air-carrier operations. Our approach involved using each of the ASMM tools in a set of (nearly) independent studies of the same operational scenario. We had the following goals:

- Demonstrate the kinds of information that each ASMM tool can contribute to gaining insight into the complete picture of an event;
- Show the methodology for utilizing each of the tools in a complementary and synergistic process of causal analysis and safety risk assessment.

The operational implications of our analysis are still under evaluation, and are presented at the end of this paper as preliminary observations. The primary purpose of this report is to present the <u>process</u> for identifying and evaluating event precursors using ASMM tools.

The scenario selected for the demonstration was changes to a landing runway assignment while on approach to the airport that we called the "In-close Approach Change (ICAC)." ATC sometimes issues clearance changes to air-carrier pilots late in the approach to expedite traffic flows and resolve traffic conflicts. Pilots can usually accommodate these clearance amendments, but sometimes they experience unwanted consequences such as unstable approaches and hard landings. The research question was whether operationally significant risks were entailed in ICAC events, and if so, how they could be minimized. Figure 1 illustrates our approach to addressing these questions using ASMM tools.

The pointer to a potentially hazardous aviation scenario could come from any data source. In this instance, it was ASRS analysts who first identified potential problems in pilots' accommodating changes to their runway assignment, altitude, or speed when close to an airport during approach. The ASRS report analyses set the stage for a more thorough examination of the problem.

Insights from the NAOMS Survey Tool

Our first step was to incorporate specific questions regarding ICAC's in the survey of air transport pilots. This provided quantitative information on the frequency of occurrence that validated the information from ASRS analysts, and it provided input on the potential seriousness of the event.

NAOMS data suggested that somewhat less than 10 percent of all air carrier approaches involve ICAC's, but there is a great deal of variability among locations. A fraction of these ICAC's are followed by unwanted events such as unstabilized approaches, hard landings, and airborne/ground conflicts. While the exact number of such unwanted outcomes cannot be obtained from NAOMS data, it would appear that it is in the tens of thousands annually. The ICAC's do not necessarily cause all of these unwanted outcomes—they might have occurred even without the ICAC. However, a reasonable conclusion from the NAOMS data is that ICAC's contribute to many of these unwanted events.

The NAOMS survey data also contributed to the characterization of the contextual factors contributing to anomalous consequences of ICAC's that are reflected in the results section of this report.

Insights from the ALAN Tool

ALAN was used to cluster a subset of 179 ASRS reports related to ICAC's spanning the period of January 1988 to August 2000. The purpose was to identify groups of related events in these reports. Operational experts assisted in characterizing the clusters identified by ALAN. ALAN identified the following primary event clusters and sub-clusters:

- External factors causing approach difficulties
  - Distraction during approach leading to procedural lapse
  - Approach change to an ILS runway
  - Landings with visibility near legal minimums
- System providing information about approach problems
  - Communication with another aircraft on takeoff
  - TCAS advisories during approach
  - ATIS providing RVR
- Issues primarily relating to larger/newer aircraft
  - Issues with use of FMS
  - Interactions with a wide-body aircraft
  - Issues involving specific approach characteristics
- Issues resulting in approach/landing procedure problems
  - STAR procedures and restrictions
  - Winds at landing and landing speed
  - Problems with cockpit automation
  - Approach plates and briefings for changed runway

The number of ASRS reports on ICAC (179) was small enough so that domain experts could read them all and correlate their evaluations of the factors entailed in the event with the automated analyses of ALAN. The experts used a structured analytical approach that we will refer to as the Cinq-Demi Method, developed in the late 1980's by a group of French researchers. (Lecomte, *et al*, 1992; Wanner, 1999) Generally, the analyses using the Cinq-Demi Method confirmed the results of the automated analyses of the ALAN tool, and contributed to some of the observations in the Results section.

Insights from PDARS Tools

PDARS used radar-track data to quantify the traffic patterns during ICAC events. One month's data for San Francisco International (SFO) and Los Angeles International (LAX) airports were used as representative samples for this study. Both airports have parallel runway configurations that are often used by ATC for "side-step" ICAC maneuvers.

PDARS was able to identify aircraft *trajectory* patterns during final approach that indicated the designated landing runway changed from one runway to another parallel runway within the last 15 miles to touchdown. PDARS tools identified the time and position of this side-step maneuver. At LAX, the average number of ICAC's per day was 22. The average time from the side-step maneuver to runway threshold was 95.8 seconds with a standard deviation of 62.0 seconds, and the average distance was 3.46 NM with a standard deviation of 2.24 NM.

At SFO, the average number of ICAC's was 11.3 per day. The average time from the side-step maneuver to the threshold was 93.3 seconds with a standard deviation of 50.7 seconds, and the average distance was 3.37 NM with a standard deviation of 1.83 NM.

Our speculation is that controllers need to wait until they are certain of their ground situation before they approve a runway change. Experienced pilots seldom have a problem executing a side-step maneuver within about 95 seconds of threshold. However, the time is short enough so that a problem *may* occur if other adverse aircraft or environmental factors exist.

Insights from APMS Tools

APMS was used to gain further insight into ICAC events by examining aircraft flight-recorded data. APMS tools were used to quantify the frequency of occurrence and the severity of consequences associated with ICAC events. This part of the study is covered by Dr. Chidester's presentation at this meeting. (Chidester, 2003) Findings from this small study sample suggest that ICAC's frequently result in less stable approaches, implying greater risk.

Insights from PROFILER Tools

PROFILER was applied to both APMS flight recorded data and PDARS radar track data to see whether it provided automated identification of patterns resembling runway changes, and "meaningful" clusters (singletons, atypical clusters) that correlated with the experts' analyses. PROFILER used APMS test data for a single carrier, and a limited number of flights, to examine recorded data parameters for the last 5 minutes of flight. PROFILER was able to identify flights that landed on a different runway than the majority in their cluster, and within this sub-cluster, to identify three flights that were ICAC candidates. Human experts agreed that two of these flights were ICACs. Using a month's worth of PDARS radar data, PROFILER examined 20,767 flights for an airport and identified 1,412 (7 percent) as potential ICAC candidates. These results were partially confirmed by a separate analysis.

Preliminary ICAC Case Study Observations

In this brief summary of our experiment, we have only presented some examples of the information we derived from the data. After integrating all of the information extracted from the various data sources (i.e., ASRS, NAOMS, flight and radar data) using the ASMM analysis tools (i.e., ALAN, PROFILER, Pattern Search, APMS, PDARS, and the Cinq-Demi Method), we hypothesized factors that contribute to the anomalous consequences of an ICAC.

These factors are presented as hypotheses, because our study was incomplete. We did not have access to all of the data that we really needed. For example, the NAOMS project has surveyed only the pilot community so far. The ATC perspective is provided to only a minor extent from ASRS reports, and these are also primarily submitted by the pilot community. We did not have as much flight data for statistical analyses as we would have preferred.

Nevertheless, we were able to gain considerable insight into the potential safety-risk of ICAC's drawn from the quantitative and qualitative data. Certainly, we can say that ICAC's contribute to a large number of unwanted consequences annually, and that these unwanted consequences are likely associated with certain factors. We can offer these additional preliminary observations on changes that might mitigate anomalous consequences of ICAC's:

- <u>ATC issuance of ICAC clearances may be problematic in relation to the following factors</u>:
  - Visual conditions from the cockpit
  - Altitude
  - Distance from airport
  - Type of equipment being flown
  - Runway configuration
- <u>Air Carrier operating practices may be vulnerable to problems related to:</u>
  - Acceptance of in-close approach changes vis-à-vis go-around
  - Response to in-close approach changes (e.g., reprogramming the automatics vs. flying on raw data)

Whether and how these insights result in changes implemented to the system are the responsibilities of the FAA and the air carriers

In the process of proactive safety-risk management illustrated in Figure 1, the steps following evaluation of the precursor events and understanding the factors involved are to formulate intervention and implementation strategies. These are the province of decision makers in industry and the FAA, because they require additional considerations such as costs and benefits that we have not addressed. ASMM has also developed tools to assist in these steps. Fast-time simulations incorporating models of human performance can be used to help evaluate proposed interventions. The outputs of these simulations are linked to analytical methods for automated risk assessments of proposed interventions. These tools were not used in our study of ICAC events.

Summary

We have demonstrated the value of using the suite of ASMM tools to assist domain experts in gaining insight into an event.

Proactive management of safety risk starts with having in place a method for continuously monitoring the performance of the system, and a capability for comparing performance to expectations, to uncover and to understand potential risks of human error. Simply saying that one or more of the humans in a system may have made a mistake is not constructive. Analyses of the quantitative databases will help the domain experts understand exactly what happened. Analyses of textual databases and narrative reports are needed to understand why. That is the essence of an approach that will take us beyond human error to proactive management of safety risk.

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